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Proceeding Paper

# Aspen Plus Modelling and Simulation of Supercritical Steam and Poultry Litter Gasification for the Production of Hydrogen Fuel and Electricity †

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**Abstract:** Because more than 75% of the world's energy needs are currently met by fossil fuels, the growing worry about climate change as well as the depletion of hydrocarbon resources has compelled scientists worldwide to discover alternative sources of renewable and sustainable energy. Hence, it has become necessary to reduce the negative effects of disposing poultry litter thereby converting it to value added product such as hydrogen fuel. By extracting energy from feedstock through the thermal gasification process, this research aims to address waste management and reduce environmental impacts. High-hydrogen feedstock is widely available. Waste poultry (biomass) and steam were used as the gasification agent in Aspen PLUS® version V 11.0 software during the modelling and simulation of the process. According to the outcome, 1000 kg/h and 2500 kg/h of the poultry litter and steam were able to yield 1220 kg/h of hydrogen and 2500 kwh of electricity. This identified poultry litter as a promising candidate to reduce fossil fuel dependency.

**Keywords:** Aspen plus®; modelling; simulation; hydrothermal gasification; poultry litter; hydrogen and electricity



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## 1. Introduction

Unsettling sustainable energy issues are brought on by an increase in energy demand, and the quick depletion of non-renewable energy sources and harmful environmental issues brought on by greenhouse gas emissions (GHE) needs development. Projections of the world's energy needs show an expanding pattern. According to estimates, annual consumption will amount to roughly 778 Exajoules (EJ) by 2035 [1]. These issues encourage scientists all over the world to focus on alternate energy sources rather than traditional fossil fuels. An earlier inquiry showed that several novel technologies were developed, many of which can convert used biomass into heat, electricity, and chemicals with additional value [2,3]. Biomass gasification is one of the finest methods for converting biomass into syngas (mostly CO and $H_2$) among all of these novel approaches [4,5]. The thermochemical conversion of biomass into gaseous fuels is known as gasification [6,7]. CO, $H_2$, $CH_4$, $N_2$, and water vapor are among the components of the producer gas produced by gasification ($H_2O$). The four stages of the gasification process are drying, pyrolysis, combustion, and reduction zone.

## 2. Materials and Methods

### 2.1. Materials

The materials used for this research work are as follows (Table 1):

**Table 1.** Materials and their uses in this research work.

| Materials | Uses |
|---|---|
| 1. Aspen Plus version 11.0 | Aspen Plus is a chemical engineering simulator used for the modelling and simulation of the design process. |
| 2. Data sheet of poultry litter | This consists of the feed specifications: 3 ultimate, proximate and composition analyses of poultry litter from an online literature review. |

## 2.2. Methods

Modelling and simulation is an integrated tool used by process engineers to design and gain insight into an existing or expected system. Aspen plus version 11.0 was used to model and simulate the use of abundant poultry litter biomass to produce hydrogen fuel and electricity via drying, decomposition and steam gasification.

### 2.2.1. Process Description

Poultry litter (biomass) processing using the Aspen Plus design model and simulation to create hydrogen and power is shown in Figure 1. The procedure is divided into four parts: drying, decomposition, steam thermal gasification/electric generation, and hydrogen production. To reduce the moisture content, the wet poultry litter was put into a dryer. The dry biomass was then transferred to a pyrolizer, where decomposition took place and produced the breakdown products C, H, N, S, and O. To raise the temperature of the gasification process by passing via the heat exchanger's tube, the disintegrated product was combined with steam. The syngas and other solid-particle-containing gasification product travels through the gas turbine to produce electricity before returning to the heat exchanger's shell and passing via a valve to the cyclone, where the fine syngas is separated from the solid. After cooling and compressing the syngas, hydrogen was extracted from the other gases using a separator.

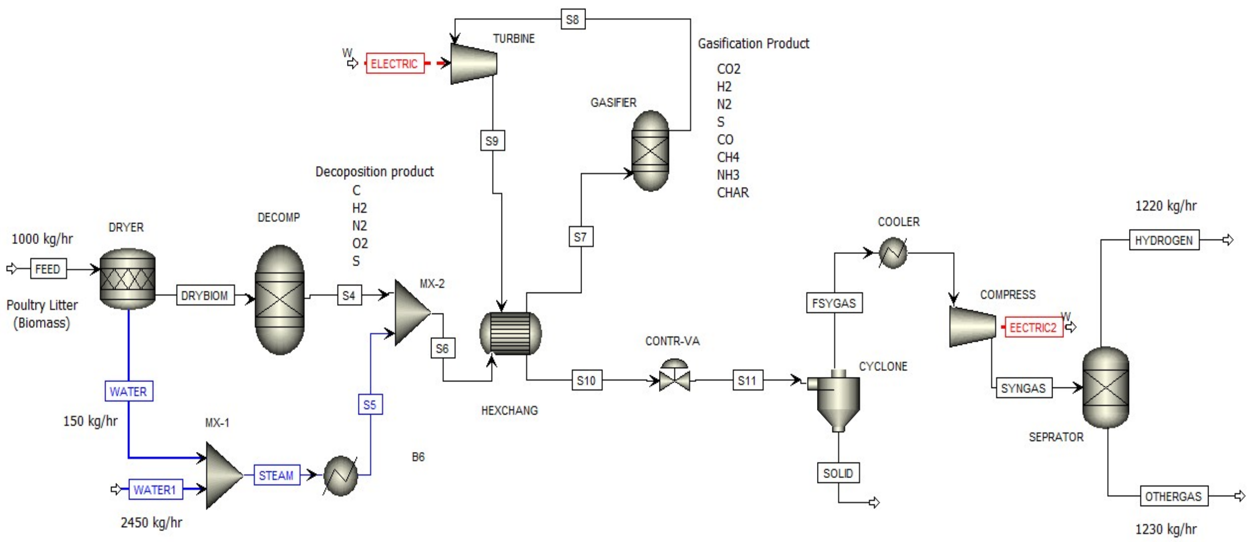


**Figure 1.** Aspen Plus design process flow diagram for the production of hydrogen and electricity using poultry litter biomass.

### 2.2.2. Modelling and Simulation

Modelling and simulation were carried out using the following steps as depicted in Figure 2. Table 2 shows the ultimate and proximate analysis of poultry litter biomass, Table 3 presented the feed-entering specifications and Table 4 is the chemical reactions involved in the poultry litter biomass steam gasification.

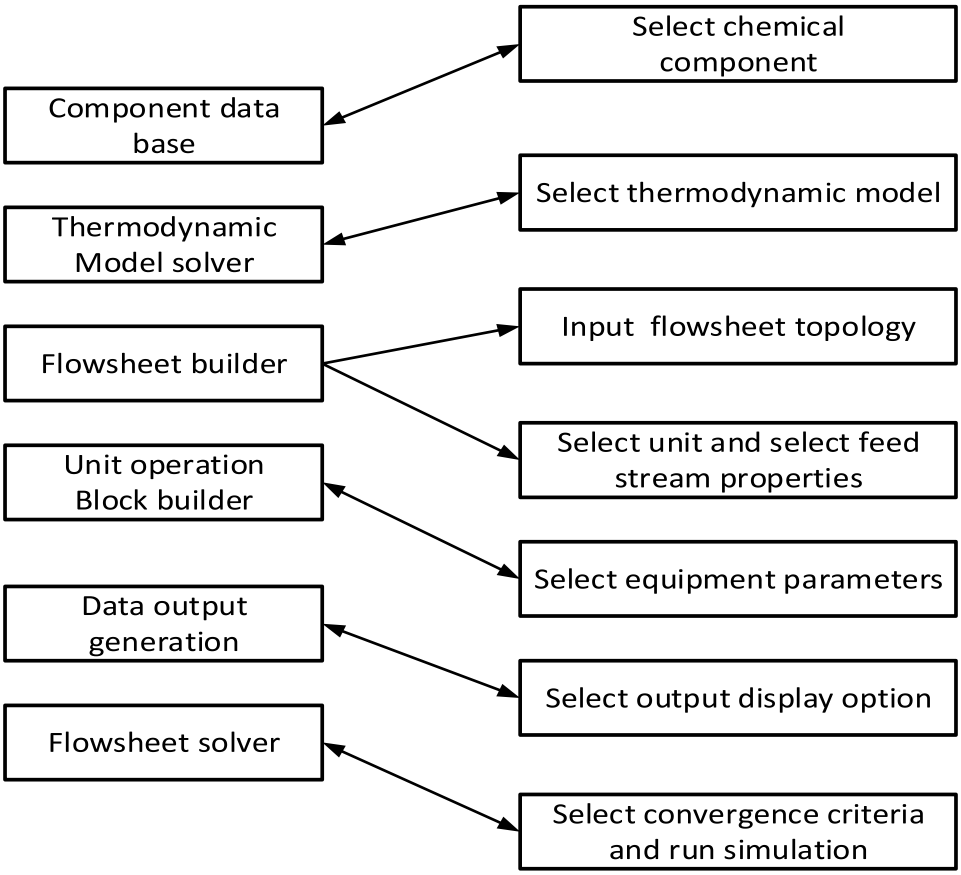


**Figure 2.** Basic modelling and simulation steps, source [8].

**Table 2.** Ultimate and proximate analysis results of waste poultry litter [9].

| Ultimate Analysis (wt. %) | Poultry Litter |
|---|---|
| Carbon | 43.98 |
| Hydrogen | 5.16 |
| Nitrogen | 4.63 |
| Oxygen | 31.98 |
| Sulphur | 0.75 |
| **Proximate Analysis (wt. %)** | **Poultry Litter** |
| Volatile matter | 63.6 |
| Fixed carbon | 15.3 |
| Moisture content | 7.6 |
| Ash | 13.5 |

**Table 3.** Feed-entering specifications.

| Feed | Amount |
|---|---|
| Biomass (Poultry litter) | 1000 kg/h |
| Temperature | 25 °C |
| Pressure | 1 atm |
| Steam | 2000 kg/h |

**Table 4.** Chemical reactions involved in the poultry litter biomass steam gasification, source: [10].

| Reaction No. | Reaction Name | Reaction Equation | Heat of Reaction ΔH(KJ/mol) |
|---|---|---|---|
| 1 | Combustion reaction | $C + O \rightarrow CO$ | −111 |
| 2 | Combustion reaction | $C + O_2 \rightarrow CO_2$ | −283 |
| 3 | Boudouard reaction | $C + CO_2 \rightarrow 2CO$ | +172 |
| 4 | Methanation reaction | $C + 2H_2 \rightarrow CH_4$ | −75 |
| 5 | Methanation reaction | $2C + 2H_2O \rightarrow CH_4 + CO_2$ | +103 |
| 6 | Water gas shift reaction | $C + H_2O \rightarrow CO + H_2$ | +131 |
| 7 | Water gas shift reaction | $CO + H_2O \rightarrow CO_2 + H_2$ | −41 |
| 8 | H2S formation reaction | $H_2 + S \rightarrow H_2S$ | −170.5 |
| 9 | Steam reforming | $CH_4 + H_2O \rightarrow CO_2 + 3H_2$ | +206 |

## 3. Results and Discussion

A hypothetical process model for the creation of hydrogen and energy utilizing poultry litter as feedstock was successfully created using Aspen PLUS® version V 11.0 software, as illustrated in Figure 1. The most persuasive parameters are the high rate of syngas composition and the temperature of gasification. The consistency of the syngas depends on the temperature at which gasification takes place. However, the results of a different study by [9] are consistent with the findings of the current study on gasification temperatures of 850 °C. According to [6], as the temperature climbed, CO and H2 concentrations rose whereas CO and CH4 concentrations fell. Additionally, the target products' results revealed that, at a gasification temperature of 850 °C, 1000 kg/h of poultry litter (biomass) and 2500 kg/h of steam, respectively, were able to produce 1220 kg/h (99.43%) of hydrogen in contrast to the highest optimum hydrogen yield obtained by [9], which was 93.2%, and 2500 kwh of electricity. This identified chicken litter as a promising candidate to lessen reliance on fossil fuels.

## 4. Conclusions

The results obtained from the modelling and simulation of the production of hydrogen and electricity using poultry litter as feedstock in the production process revealed that the developed model was successful. The model was able to converge when simulated using the non-random two-liquid model as the fluid, a gasification temperature of 850 °C gave the best yield of hydrogen at 1220 kg/h, and 2500 kWh of electricity was generated.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ECP2023-14723/s1, Reference [11] is cited in the supplementary materials.

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**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The results obtained from this work showed that a commercial-scale plant design that can convert poultry litter to hydrogen and electricity is a possibility. The work established that the hydrogen and energy yields of 1220 kg/h and 2500 kWh, respectively, can be obtained with a biomass to steam ratio of 1:2 (1000 kg/h:2000 kg/h).

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**Conflicts of Interest:** The authors declare no conflict of interest.

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