

Experimental investigation of sewage sludge solid waste conversion to syngas using high temperature steam gasification

Uisung Lee, Jun Dong, J.N. Chung*

Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL 32611, United States

ARTICLE INFO

Keywords:

Steam gasification
Sewage sludge
High temperature
Waste
Dynamics
Carbon conversion
Batch process

ABSTRACT

Sewage sludge from wastewater treatment facilities needs to be treated before it can be disposed of. While it is typically processed through an anaerobic digestion process, sludge can also be a good feedstock for alternative fuel production. High-temperature steam gasification is a process that decomposes organic materials into synthesis gas (syngas) with a high hydrogen concentration. In this study, a lab-scale steam gasification system which converts sewage sludge into valuable syngas was developed and experimentally evaluated. This study specifically focuses on investigating the chemical kinetics of syngas generation and feedstock decomposition in a batch process. The syngas generation rates and concentrations of syngas constituents were measured, and changes in carbon balance during gasification were tracked with respect to time, which shows how reaction rates vary over time. It was found that variations in steam flow rates modified the gasification reactions both thermodynamically and hydrodynamically. The gasification processes were fitted into logistics curves to understand the effects of different steam flow rates. The results indicate that the chemical reaction velocity can be controlled to achieve optimum operating conditions, which potentially can reduce both processing time and steam consumption while maximizing the syngas yield. This study would contribute more to the complete understanding of the sewage sludge gasification processes and the kinetics of the gasification chemical reactions.

1. Introduction

In the United States, publicly owned wastewater treatment plants process 130.5 Gl/d of wastewater and generate millions of tons of sludge annually [1]. Sewage sludge is an abundant resource which would be disposed of unless it is utilized. It is homogeneous with high energy content, which makes it an appropriate type of feedstock for energy production. Because it is carbon-neutral from a biogenic resource, it is expected to reduce fossil fuel usage and greenhouse gas emissions significantly.

In order to dispose of sewage sludge properly, treatment processes are needed to meet disposal regulations requiring to reduce odor and pathogens [2]. Anaerobic digestion processes are typically used to manage sewage sludge. Produced biogas mainly contains methane (CH_4), which is typically flared to decrease global warming impact. However, CH_4 may leak before it is captured and flared. Considering that CH_4 has around 30 times higher global warming potential than that of carbon dioxide (CO_2) over 100 years [3], even a small amount of CH_4 emission can be a huge threat for global warming. Digestate, a residual of the anaerobic digestion process, is still digestible which emits extra CH_4 once it is landfilled or applied to soil.

A steam gasification process can be considered as a feasible alternative sludge treatment process while it converts sewage sludge into useful fuels. This process is a highly efficient energy conversion process which converts most organic fractions into gaseous fuels through thermochemical reactions. It reduces the amount of residue much more than conventional anaerobic digestion pathways. Since generated synthesis gas (syngas) has high hydrogen (H_2) concentrations, it is regarded as an economical H_2 production pathway. Most H_2 is currently generated via steam methane reforming processes of natural gas. Thus, the steam gasification process can be an alternative method to generate H_2 using waste resources.

Steam gasification increases the quality of syngas compared to conventional air gasification by avoiding dilution caused by nitrogen in the air. There have been analytical and experimental research on steam gasification using sewage sludge. Choi et al. [4] focused on investigating the effect of activated carbon, which facilitated the production of H_2 -rich and tar-free syngas. Li et al. [5] studied the steam gasification of sewage sludge specifically on the effect of bioleaching and reactor temperature. It was found that bioleached sewage sludge led to reduced heavy metal content, and higher temperatures resulted in H_2 -rich syngas with high syngas yield. Akkache et al. [6] performed

* Corresponding author.

E-mail address: jnchung@ufl.edu (J.N. Chung).

Nomenclature

Ar	Archimedes number
D	diameter
k	slope steepness constant
$m_{c,feedstock}$	mass of the carbon in feedstock
\dot{m}	mass flow rate
r	carbon ratio
Re	Reynolds number
t	instantaneous gasification time
t_f	total gasification time
U	velocity

Greek symbols

χ	carbon conversion
--------	-------------------

μ	viscosity
ρ	density
τ	normalized gasification time
ξ	remained carbon

Subscripts

g	gas (steam)
p	feedstock particle
mf	minimum fluidization
i	gas component
f	final

Abbreviations

sccm	standard cubic centimeters per minute
------	---------------------------------------

experimental evaluation of the steam gasification of various feedstocks including sewage sludge to find an optimal gasification blend. Instead of using sewage sludge directly, Gai et al. [7] used hydrochar derived from sludge to evaluate the impact of the pretreatment process. Hu et al. [8] studied the co-gasification of wet sewage sludge and pine sawdust to optimize the use of wet sludge that typically requires energy intensive pre-drying processes. Schweitzer et al. [9] evaluated the steam gasification of sewage sludge specifically focusing on the concentration of impurities such as tar, ammonia (NH_3), hydrogen sulfide (H_2S) and chlorine (Cl) in syngas.

These studies show that steam gasification could be a good option for sewage sludge treatment while generating syngas with a high H_2 concentration. Despite all these efforts, no data regarding the dynamics of pure steam gasification of sewage sludge is available. Considering that the gasification process involves a set of successive chemical reactions, it is needed to measure time dependent syngas yield and concentration data to understand the underlying characteristics of steam gasification reaction dynamics.

In that sense, evaluating changes in syngas production and concentration is important. In this study, a mass spectrometer was used to measure and record the syngas concentration data in real time. Additionally, gas flow meters were used to measure the rate of syngas

generation. Integrating these two data sets led to time-dependent syngas production curves which show rising and falling of each syngas constituent production rate. This study would help understand the time dependent characteristics of the steam gasification of sewage sludge, and eventually facilitate the evaluation of the chemical reaction processes. Details of the dynamic conditions of the steam gasification are discussed in this paper using experimental data.

2. Experimental system setup and procedure

Fig. 1 shows an experimental system used in this research. It consists of five major subsystems – a high temperature steam generator, a reactor, a syngas cleaning and cooling unit, a data acquisition unit, and a feedstock loading unit. First, deionized water in a reservoir was pumped to the steam generator, and the saturated steam exiting from the steam generator headed to high-temperature furnace superheaters to be heated up to 1000°C . The 1000°C steam then entered the reactor, a vertical alumina tube with a diameter of 76 mm, surrounded by two cylindrical electric furnaces to maintain the desired reactor temperature. Alumina was chosen as the reactor material because it eliminates the potential chemical reaction between the reactor tube surface and the steam, while it also works as a catalyst to reduce tar formation [10].

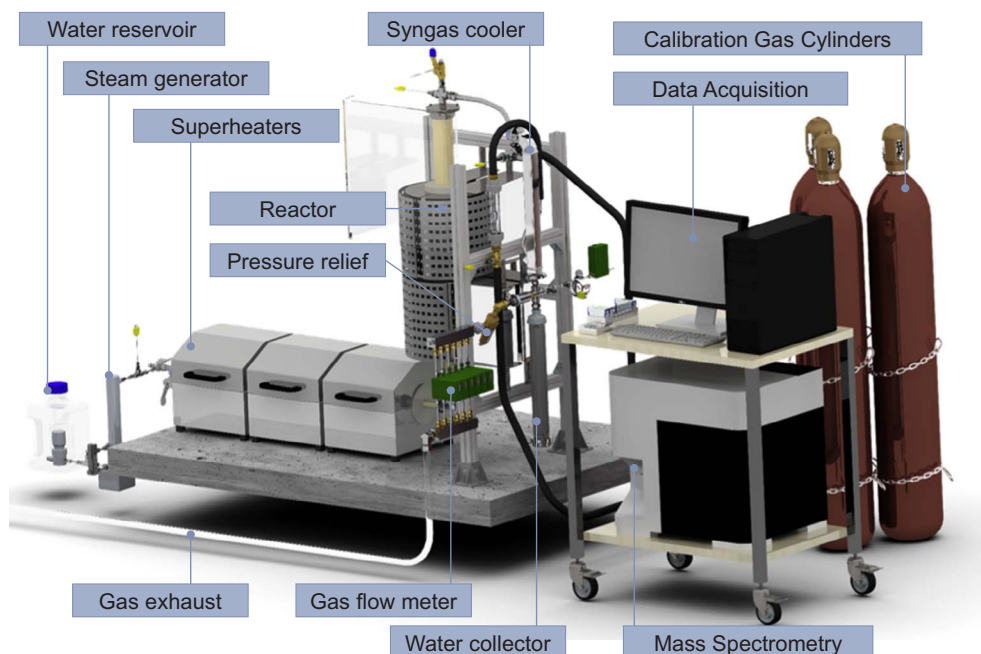


Fig. 1. Three dimensional model of the overall steam gasification system and its components.

Download English Version:

<https://daneshyari.com/en/article/7159161>

Download Persian Version:

<https://daneshyari.com/article/7159161>

[Daneshyari.com](https://daneshyari.com)