Experimental and modelling investigation on the gasification of the sludge for Hydrogen production

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1. INTRODUCTION

Persistent production and disposal of sewage sludge from wastewater treatment plants present ongoing socioeconomic and environmental challenges (Bagheri et al., 2023). Global production is consistently rising, estimated at 45 million tons annually in 2017 and projected to reach 127.5 million tons by 2030 (Mateo et al., 2015). Sewage sludge contains organic pollutants, heavy metals, pathogens, and pharmaceuticals, posing significant hazards. Managing sludge incurs substantial economic costs, with disposal expenses ranging from 160 to 310 euros per ton (Ferrentino et al., 2023). Traditional treatment methods, including incineration and landfilling, face regulatory hurdles and environmental concerns. Alternative methods like gasification offer potential benefits but require further exploration and evaluation as substitutes to conventional approaches. In this study the experimental investigation on gasification of two sewage sludge samples, followed by equilibrium and numerical modelling inside the entrained flow gasifier is studied.

2. METHODOLOGY

2.1 Material characterization

Thermogravimetric analysis (TGA), elemental analysis, and bomb calorimetry were applied to two sets of samples of sewage sludge. Fig. 1 depicts the TGA curves of SS1 from Dubai electricity and water authority (DEWA), SS2 from municipal water and sewage utility of Rethymno (MWSUR). Table 1 lists the proximate, ultimate, and calorific analysis values for the two samples. Dried sewage sludge is a byproduct of wastewater treatment that contains both organic and inorganic components. TGA was used to perform proximate analysis on sewage sludge mixture. Measurements were conducted using Thermo-scientific STA TA Q600 apparatus with air flow rate similar to previous studies (Shabbar et al., 2013). Ultimate analysis and heating values were obtained using Thermoscientific flash CHNS-O analyzer and Parr bomb calorimeter.

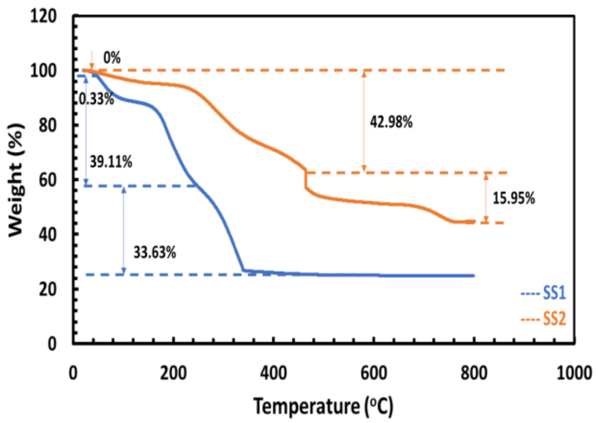

Fig. 1. TGA curves of SS1 and SS2

Table 1: Proximate and ultimate analyses of different samples of sewage sludge

Sample	***SS1*** $CH_{1.9153}N_{0.0918}S_{0.0442}O_{0.3183}$	***SS2*** $CH_{1.5229}N_{0.1181}S_{0.0143}O_{0.3086}$
Proximate analysis	**Mean**	**Mean**
Moisture (Wt%)	0.33 ± 0.01	0
Volatile (Wt%)	39.11 ± 0.01	42.98 ± 0.01
Fixed carbon (Wt%)	33.63 ± 0.01	15.95 ± 0.01
Ash (Wt%)	26.93 ± 0.01	41.07 ± 0.01
Ultimate analysis	**Mean**	**Mean**
C (Wt%)	55.17 ± 0.01	34.79 ± 0.01
O (Wt%)	23.46 ± 0.01	14.32 ± 0.01
H (Wt%)	8.85 ± 0.01	4.42 ± 0.01
N (Wt%)	5.98 ± 0.01	4.80 ± 0.01
S (Wt%)	6.53 ± 0.01	1.33 ± 0.01
HHV (MJ/kg)	14.75 ± 0.2	12.75 ± 0.2

2.2 Experimental setup

The atmospheric drop tube reactor (DTR) developed for waste to energy research, comprises a rectangular stainless-steel furnace equipped with insulation and heating modules. It integrates 15 K-type thermocouples for temperature monitoring and gas sampling facilitated by suction pump long stem needles. With the capability to reach temperatures up to 1400 K, the reactor tube serves as the locus for the gasification process. Additionally, the setup incorporates a gas delivery system for supplying oxidant and nitrogen, a particle injection mechanism for introducing feedstocks, and diagnostic instrumentation for assessing temperature and gas concentrations. The experimental configuration is illustrated in Fig. 2, while detailed specifications of the furnace and tube are delineated in Table 2.

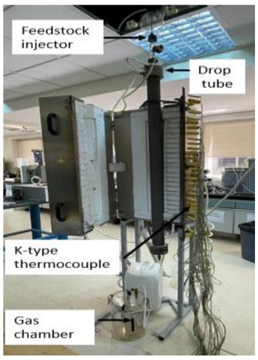

Table 2: Detailed specification of the DTR

Parameter	***Value***
Heated length	750 mm
Length of tube	1540 mm
Outer diameter of tube	75 mm
Inner diameter of tube	66 mm
Power rating	4.6 kW
Maximum temperature	1400 K
Material of the tube	APM
Gas volume flow rate	100-1000 l/h
Particle mass flow rate	0.033-33 g/min

Figure 2. Experimental setup

2.3 Numerical modelling

A novel computational fluid dynamics (CFD) model assesses gasification of two sewage sludge samples in a drop tube reactor. Unlike equilibrium-based models, it prioritizes events and kinetics, considering temporal and spatial variations in reactive flow. The model accurately incorporates gasifier geometry, heat losses, turbulence kinetics, and species behavior for realistic efficiency evaluation. The reactor resembles in experimental set up section, featuring an upright tube (1540 mm x 66 mm diameter) for feedstock and oxidizer inlet. The computational domain comprises 120,500 finite volume quadrilateral cells with a multi-blocking technique for meshing. Conservation equations for mass, momentum, energy, and species movement govern the simulation, accounting for two-phase (solid and gas) chemically reacting environments.

3. RESULTS AND DISCUSSION

The optimal gasifier temperature of 1,250°C based on the equilibrium model was imposed in the high fidelity modeling. Oxidizer and moderator addition at the intake enabled gasification equivalence ratios. Sewage sludge SS1 and SS2 were introduced using the discrete phase model. Fig. 3 illustrates SS1 mole fraction of gasification yield. The early CO and H_2 mole fraction conversion was less because of the low temperature. Feedstock composition significantly influences CO and H_2 ratios, with higher reactor temperatures promoting CO and H_2 production while decreasing CO_2 and H_2O due to enhanced endothermic char reactions. Ongoing experimental and high-fidelity modeling of sludge gasification is currently pursued in our lab and reporting on these results is underway.

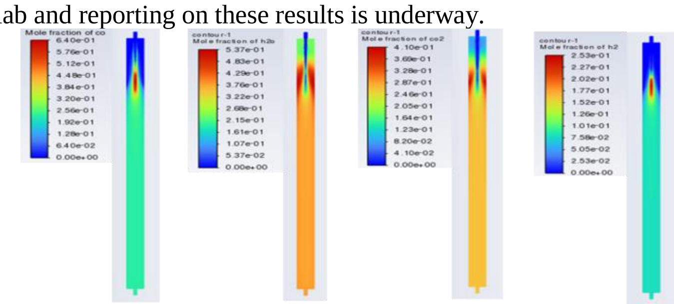

Fig. 3. Temperature influence on gasification products and CGE for SS1

4. CONCLUSIONS

The surging production of sewage sludge necessitates effective treatment, especially in Middle Eastern regions like the UAE and European areas like Greece. Conventional disposal methods are insufficient due to the composition and potential hazards of sewage sludge. Here we advocate thermochemical recovery of sewage sludge gasification, as a promising solution. Meticulous analyses, encompassing proximate, ultimate, and calorific assessments, alongside numerical modeling, underscore the potential for establishing a sustainable treatment approach. Therefore, thermochemical conversion of sewage sludge could stand as a viable method for energy generation and regulation of the anticipated global increase in sewage sludge.

5. REFERENCES

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