Thermal Behavior of Waste-derived Fuels and Determination of Optimum Mixture Ratio for Gasification

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ABSTRACT

The study focused on determination of thermal behavior of waste-derived fuel under air and air-free conditions. Thermochemical processes are commonly used as waste management options in order to produce energy and minimize the amount of solid wastes. Since the population all over the world is rising, the general concern becomes to find alternative ways to manage all types of waste in an economic manner as increasing the process efficiencies. Treatment sludge, with its complex matrix, needs special attention to prevent environment from its adverse effects in case any contamination. The main idea in this paper is to increase energy content of waste-derived fuel by mixing solid and liquid wastes. As a solid waste, treatment sludge (raw sludge) from a domestic wastewater treatment facility was selected. Waste cooking oil (used oil) was used as liquid form to increase calorific value of waste mixture before gasification experiments. Elemental carbon content of raw sludge increased from 27% (mass) to 32% and 37% after preparing a proportion of 1/5 oil/sludge and 2/5 oil/sludge, respectively. Thermochemical behavior of those mixtures were analyzed by Thermal Gravimetric Analysis (TGA) technique. Optimum proportion for gasification of waste-derived fuel was determined as 40%, which also prevents the mixture to behave like a liquid due to viscosity. Syngas had a calorific value of approximately 2700 kcal/m^3.

Keywords: Gasification, Energy, Waste to Energy, Syngas.

INTRODUCTION

Gasification is a set of chemical reactions that uses limited oxygen at high temperatures (>700 ºC) to degrade a carbon fuel into a syngas with high calorific value (Ongen, 2016; Ozcan et.al., 2016). CO, H_2, CH_4 are main gases which form syngas. The composition of syngas depends on reactor type, fuel type, operational temperature and heating rate. The dried sewage sludge could be considered to be a special type of biomass due to the high quantity of organics and the sufficiently high calorific value of the sludge (Ongen *et.al.*,2015). The sludge production rate in Turkey is around 60 g/person-day which makes it a great opportunity to be used as an alternative energy resource. Landfill storage and agricultural applications are commonly used for final sewage sludge management in many countries that are technologically less developed. Thermal disposal methods are applied in developed countries where direct land applications are forbidden. Therefore, gasification is a reliable technology that producer gas can be burned to release energy or used for production of value-added chemicals. Gasification prevents emissions of sulfur and nitrogen oxides due to reducing atmosphere (Ongen et.al., 2017). Additionally, heavy metals and the potential production of chlorinated dibenzodioxins and dibenzofurans are limited related to the air-limited atmosphere. There are numerous studies about gasification of different types of sludge in the literature (Kokalj *et.al.*, 2017; Judex *et.al.*, 2012; Striūgas *et.al.*, 2017; Werle, 2015).

MATERIAL AND METHODS

Sludge from domestic wastewater treatment plant was used as a fuel in the studies. The samples were used directly without pretreatment. The waste oil used in the mixture samples was obtained from houses.

Analyzes such as moisture, amount of solids, loss of combustion, amount of ash were carried out in accordance with Standard Methods (21th Edition).

Elementel analysis

The elemental analysis of raw fuels, solid and liquid products after gasification were carried out to monitor the change in carbon amount both before and after gasification experiments. C, H, N and S content of the samples were determined. Elemental analysis experiments were carried out with the Thermo-Flash 2000 CHN-S elemental analysis instrument, which was obtained within the scope of the project numbered TR10/14/EVK/0022 (by Istanbul Development Agency) in the Istanbul University Environmental Engineering Department laboratory.

Thermogravimetric analysis

Linseis brand STA PT 1750 model thermogravimetric analysis (TGA) device was used in the laboratory of Department of Chemical Engineering of Istanbul University-Cerrahpaşa to determine thermogravimetric behavior of fuels.

Calorific (Heating) value analysis

The calorific value analysis of the sludge samples used in the study and of the solid liquid products produced after the process were performed. This analysis was carried out using the IKA C200 Bomb Calorimetry, which was provided within the project supported by Istanbul Development Agency TR10/14/EVK/0022, located in the laboratory of the Department of Environmental Engineering, Istanbul University-Cerrahpaşa.

Gasification experiments

Gasification refers to a process that converts biomass into valuable gas with calorific value in the oxygen starving media. Gasification experiments were performed at 750 ^oC in the presence of 0,05 l/min limited dried air in a lab-scale fixed bed steel reactor with cyclone separator. CO, H_2, CH_4, content of producer gas was monitored by an on-line gas analyzer. Calorific values were calculated depending on the composition of each producer gas. Figure 1 shows the schematic diagram of gasification reactor.

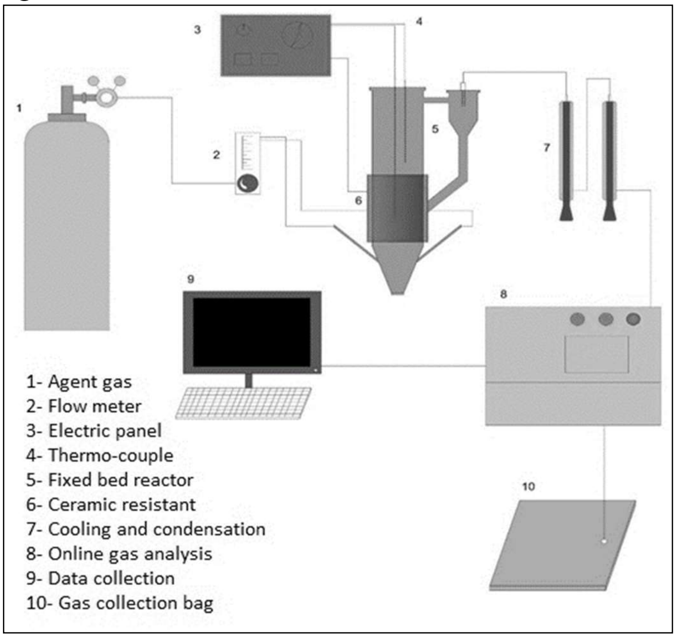

Figure 1. Schematic diagram of gasification reactor.

RESULTS AND DISCUSSION

Elemental characterization and calorific values of each waste type were given in Table 1.

Table 1. Elemental analysis and calorific values of raw sludge and fuel mixtures

Type of Fuel	C (%)	H (%)	N (%)	S (%)	Calorific Value (kcal/m^3)
Raw sludge	27,0	3,9	4,3	-	2700
Mixture – 1/5 – oil/sludge	32,1	4,67	2,8	-	3538
Mixture – 2/5 – oil/sludge	37,7	4,9	3,6	-	4178
Used cooking oil	-	-	-	-	9200

As seen in Table 1, both carbon content and calorific value of fuel increased due to used oil content. Those results confirms that mixture of those two different waste types enhanced fuel characteristics before thermochemical utilization.

Figure 2 shows the heating rate of gasification reactor to the final point at 700 ºC. Due to energy loss during heating, the heating rate reduces as the temperature rises. An exponential trendline was accepted for the heating rate during gasification experiments.

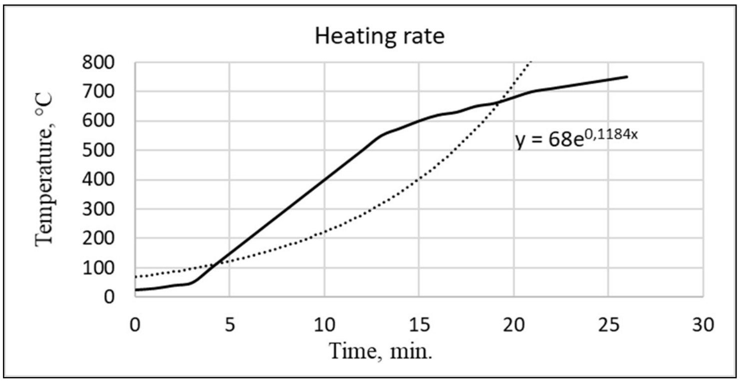

Figure 2. The heating rate of gasification reactor

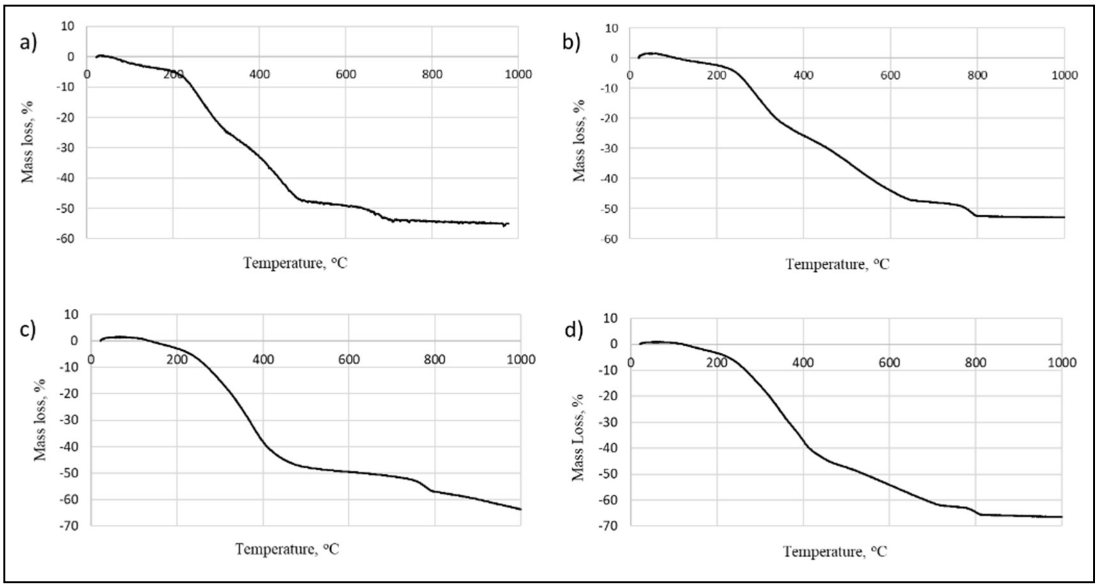

Figure 3. a) Raw sludge-Nitrogen-TGA b) Raw sludge-Nitrogen-TGA
c) Raw sludge-Air-TGA d) Raw sludge-Air-TGA

TGA results in two different media are compared as given in Figure 3. Air oxidation resulted higher volatilization and mass loss in the samples where limited volatilization was determined in nitrogen media. 55% and 65% mass losses were detected during TGA, respectively. The results revealed that the sludge had high inert content over 45%.

Figure 4 presents the results of gasification experiments with a 1/5 mixture ratio. The percentage of CH_4 in the synthesis gas reached 25%, H_2 gas has risen to about 20% while CO was detected at 10%.

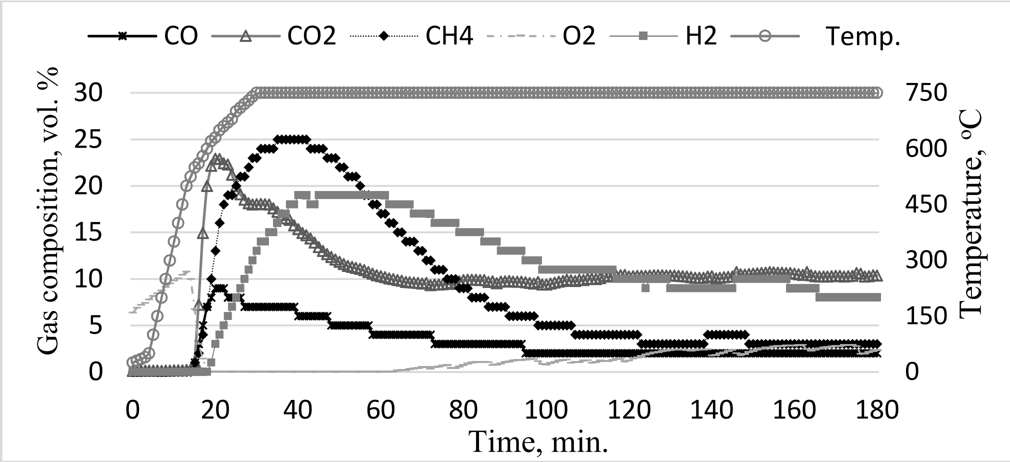

Figure 4. Gasification results of 1/5 sludge-oil mixture.

In particular, the fact that the maximum levels of H2 and CH4 gases are measured at the same time around 40th minute causes the calorific value of the produced synthesis gas to increase in the same way.

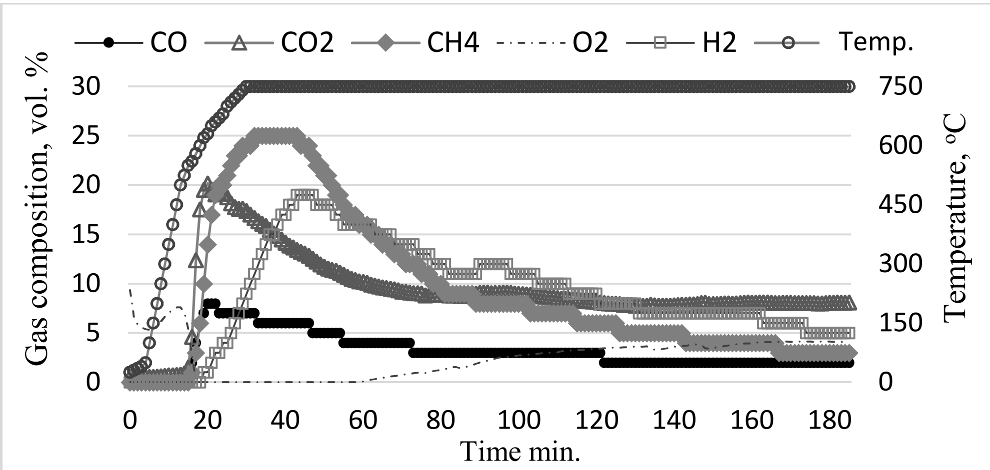

Figure 5. Gasification results of 1/5 sludge-oil mixture.

Gasification (G) experiment was carried out in order to identify the most suitable mixture proportion of oil/sludge at 700 °C with 0,05 l/min of gasification agent flow. Calorific value of each producer gas after gasification experiments were calculated and given in Figure 6.

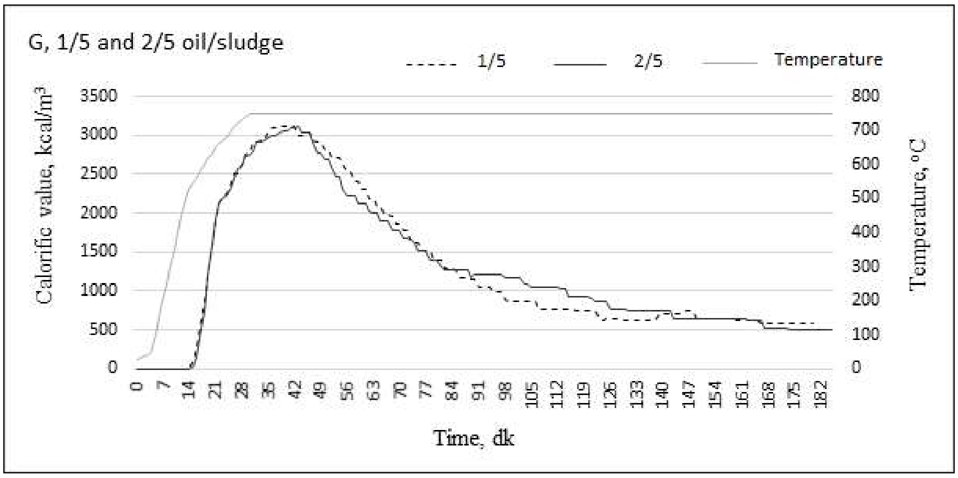

Figure 6. Calorific values of producer gas via gasification of varying mixture proportions.

Table 2 compares the calorific values of some gaseous fuels.

Table 2. Higher Heating Value (HHV) for some common fuels

Gaseous Fuel Type	Calorific value, kcal/m^3
Hydrogen	3035
Methane	9512
Acetylene	13073
Natural gas (US marked)	9703
Town gas	4302
Syngas (produced in this study)	3100

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Gasification of both mixtures resulted similar calorific values around 3100 kcal/m^3, which is higher than hydrogen involves. As seen in Table 2, gasification of domestic sludge in a fixed bed reactor achieved to produce a syngas almost equal to town gas.

CONCLUSIONS

Thermal behavior of waste-derived fuel in different media and optimum proportion for fuel mixture was determined in the study. The conclusions regarding the experimental data were given below.

- Domestic sludge can be used as alternative energy source due to calorific content. Sludge used in this study has a calorific value of 2700 kcal/m^3.
- Used cooking oil has very high calorific value of 9200 kcal/m^3 that makes it a valuable energy stock covered in its chemical bonds.
- The combination of these two waste type generated a fuel with more elemental carbon and higher calorific value. That helped improve syngas composition to decide the most suitable mixture ratio.
- Figure 6 showed that it is possible to produce syngas with a calorific value over 3000 kcal/m^3. Syngas with a calorific value almost equal to town gas was achieved via gasification in a fixed bed reactor.

- H_2 and CH_4 percentages in syngas were determined around 20% and 25%, respectively. At least 50 percent of the produced synthesis gas was composed of these three gases with energy content.
- Limited experiments were given in the study with very limited changing parameters only to evaluate if gasification could be used for a management alternative of treatment sludge. Even in that case, syngas with economic value could be produced.
- Future studies need to be conducted on effect of varying heating rates, reactor types, operational temperatures, gasification agent etc. to optimize the process and understand the way of increasing gasification efficiencies.

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