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# THERMAL DEGRADATION MECHANISM OF SEWAGE SLUDGE

B. Kamal Batcha and V. Kirubakaran
Centre for Rural Energy, The Gandhigram Rural Institute - Deemed to be University, Gandhigram, Tamil Nadu, India
E-Mail: kirbakaran@yahoo.com

## ABSTRACT

Disposing of Sewage Sludge is the major concern in waste management. Several studies have already been carried out on thermal degradation. Thermogravimetric studies on sewage sludge reveals that the sewage sludge is an ideal bio-residue for gasification process. This paper attempts in arriving mechanism of thermal degradation of sewage sludge. A batch type rector has been developed and heated externally using an muffle furnace. The product gas has been continuously analyzed and reported. From the gas evolved the rate reaction is arrived and verified.

**Keywords:** sewage sludge, TGA, mechanism.

## INTRODUCTION

Bio residue will be the future fuel for power generation as well as thermal application. These bio residues are the by products from the agro based industries / process. The sewage sludge also one of the bio residue from the effluent treatment plant. Much research has been concentrated to disposed of the sewage sludge. Most of the studies reported that thermo chemical conversion route seems to be the best alternate.

TGA studies have been carried out to study in depth of the degradation rates in the sewage sludge. Based on the thermal degradation first order kinetics has been proposed. Activation energy and order of reaction has been evaluated for both devolatilization kinetics as well as combustion kinetics.

However to design a combustor / gasifier, a mechanism should be arrived. The mechanism will predict, the gases will be evolved during the degradation. Hence the proposed investigation will aim in developing mechanism for the sewage sludge in the batch reactor.

## Experimentation

A gasifier was fabricated, similar to the static batch gasifier used for gasification experimental studies by Williams and Besler (1993, 1996). The constructional details of the fabricated static batch gasifier is described in Figure-1.

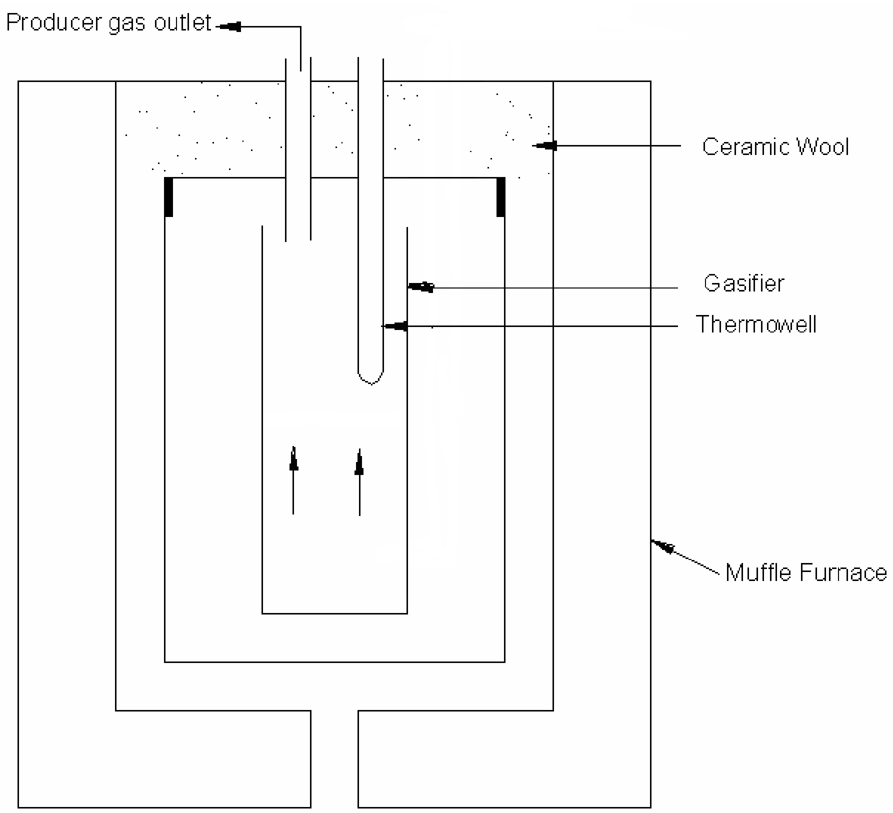


**Figure-1.** Static batch gasifier.

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A cylindrical vessel is used as a gasifier made up of SS304 stainless steel, which measures 6 cm diameter, 12 cm height and around 350 cc volume. The lid of the gasifier has a provision for gas outlet and for measurement of temperature of the gasifier. For temperature measurement, a K-Type thermocouple is attached to the lid. The entire gasifier unit with the sample is kept inside a muffle furnace for indirect heating of the sample. A condenser is provided to condense the output of the gasifier, which separates the liquid fuel from the gaseous products. The rest of the products from the outlet is sent for analysis.

A sample of sewage sludge is weighed 10 grams was taken in the fabricated static batch gasifier. Before placing the gasifier in the furnace, the lid of the gasifier is examined and ensured for airtight closure. The Muffle Furnace used for this experimentation has a rating of 230V, 15A, 3.75W and 1200 °C Maximum Temperature. After selecting a heating rate of 5 $^{o}$C min$^{-1,}$ the muffle furnace was switched on and cooling water was allowed to pass through the condenser. A producer gas analyzer is employed to analyze the compositions of major constituents CO, $CO_2$, $CH_4$ and $H_2$ in the product gas continuously.

## RESULT AND DISCUSSIONS

The TGA studies on sewage sludge clearly indicates that de-volatilization started around 200 $^{o}$C and completed around 500 $^{o}$C. The gasification of char is started to commence from 500 $^{o}$C onwards. The methane composition in the gas mixture is reduced above 500 $^{o}$C whereas the analyzer records CO composition steadily.

The expression for the rate of reaction of a solid particle is simply the mathematical representation of conceptual model. If the model corresponds to reality, the rate expression derived from the model will closely predict and describe the actual kinetics.

The mathematical analysis based on a model, which does not correspond with reality is worthless for an engineer in making design predictions. The requirement for a model from which to develop the kinetic equations is that it should closely represent the actual phenomena, which can reasonably be treated without undue mathematical complexities.

The de-volatilization of sewage sludge may be written as

$$C_{2.85}H_{5.8}O_{1.51} \longrightarrow \lambda_1\, CO + \lambda_2\, CO_2 + \lambda_3\, CH_4 + \lambda_4\, H_2O + \lambda_5\, C \quad (1)$$

Where, λ is the stoichiometric coefficient of each of the component per mole of methane formed?

$$\frac{1}{\lambda_3} C_{2.85}H_{5.8}O_{1.51} \rightarrow \frac{\lambda_1}{\lambda_3} CO + \frac{\lambda_2}{\lambda_3} CO_2 + CH_4 + \frac{\lambda_4}{\lambda_3} H_2O + \frac{\lambda_5}{\lambda_3} C \quad (2)$$

Since, CO forms during de-volatilization as well as gasification of char ($\lambda_1/\lambda_3$) will not be the true representative. Therefore the ratio ($\lambda_2/\lambda_3$) [moles of $CO_2$ formed per mole of $CH_4$ formed] is compared with experimental ratio composition

$\lambda_2 / \lambda_3 = 2.2$

The following devolatilization reaction mechanism is found to give this ratio approximately:

Per mole of volatile matter,

$$C_{2.85}H_{5.8}O_{1.51} \longrightarrow 0.32 CO + 0.5\, CO_2 + 0.23\, CH_4 + 2.44\, H_2O + 1.8\, C \quad (3)$$

The 1.8 moles of char reacts with 1.8 moles of water formed due to reaction (3) and 0.64 moles of water available as moisture. Thus the gasification of char becomes

$$1.8\, C + 1.8\, H_2O \longrightarrow 1.8\, CO + 1.8\, H_2. \quad (4)$$

The TGA studies clearly indicate that gasification of char commences from 500 $^{o}$C onwards. Therefore the char formed from 200 $^{o}$C to 500 $^{o}$C gets accumulated and finally gasified to CO and $H_2$.

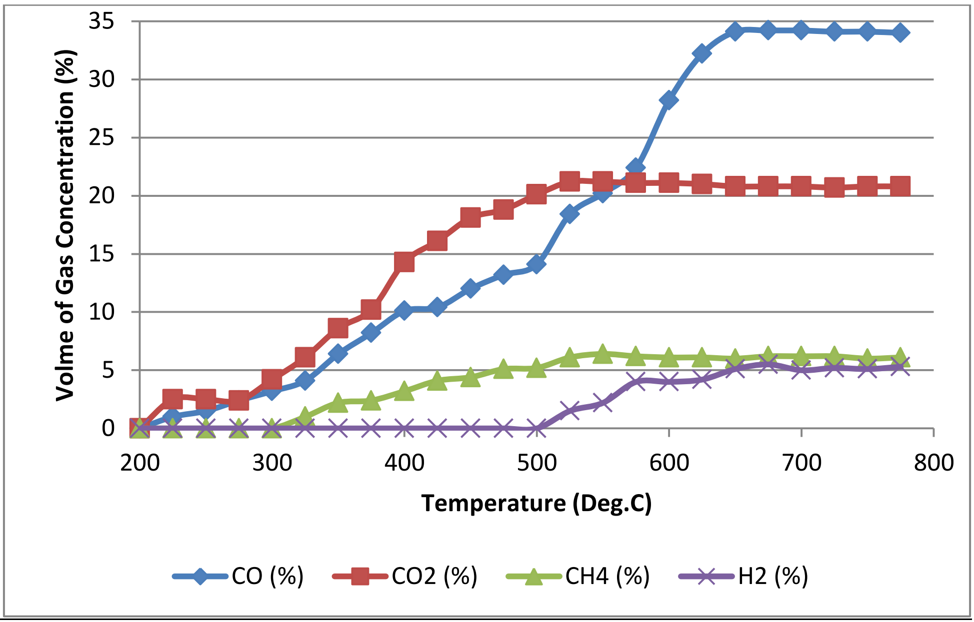


**Figure-2.** Gas formed in batch reactor.

Therefore the overall reaction is divided into two regions. In the first region, the decomposition of sewage sludge takes place between 200 and 500 $^oC$ as per Reaction (3) and in the second region, the gasification of char takes place between 500 $^oC$ and 800 $^oC$ as per Reaction (4) The cumulative volume percentage of each component are plotted in Figure-2.

## CONCLUSIONS

Based on the compositions of various gases obtained in a Static Batch Gasifier, the mole ratios of CO and $CO_2$ to $CH_4$ were calculated at temperatures ranging from 200 $^oC$ to 800 $^oC$. From the average of ratios obtained the thermal degradation mechanisms has been proposed. The thermal degradation of sewage sludge takes place in two stages: Between 200 and 500 °C, the devolatilization takes place with char formation and above 500°C, the gasification of char commences The moles of each of gaseous component that would have formed as per above reactions are found to match satisfactorily with those calculated using TGA data and composition ratios proving the validity of the reactions mechanism.

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